Journal of Applied Ecology 1993, **30**, 25–30

Effects of recreational scuba diving on coral reefs: trampling on reef-flat communities

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Summary

1. This study investigated the effects of trampling by scuba divers and snorkellers on reef-flats of coral reefs near Sharm-el-Sheikh, a popular resort in Egypt.
2. There were significantly more damaged coral colonies and loose fragments of live coral in heavily-trampled than in little-trampled areas. Percentage cover of bare rock and rubble was also significantly greater; conversely, numbers of hard coral colonies and total percentage live coral cover were lower.
3. Coral colonies were smaller in trampled compared to control areas, with average height and diameter significantly less in heavily-trampled areas. An area regularly visited by snorkellers exhibited intermediate effects.
4. Coral species composition and the relative abundances of different coral growth forms did not appear to be affected by trampling.
5. Several of the effects detected differed between outer and middle zones of the reef-flat, suggesting that some communities were more vulnerable to trampling than others.
6. In addition to causing biological damage, trampling reduced the aesthetic appeal of the reef-flat for tourists. An effecttive management strategy might therefore be to contain trampling within narrow areas rather than allowing free access by divers.

Key-words: human impact, management, Red Sea, snorkelling, tourism.

Journal of Applied Ecology (1993) **30**, 25–30

Introduction

In recent years scuba-diving has become an increasingly popular recreational activity. As coral reefs have become more accessible and facilities for visitors improved, the number of people diving on this potentially fragile ecosystem has risen. There is now widespread concern that significant reef degradation has resulted from tourism (Salm 1986; Ward 1990). However, little work has been done so far on the effects of divers and snorkellers on reefs (Tilmant 1987): Information on such effects is a preliminary and essential component for any coral reef management strategy and is necessary for calculating the carrying capacity of reefs for tourism. This study was designed to investigate the effects of trampling by divers and snorkellers on coral reef-flats.

Methods

Sharm-el-Sheikh, on the Egyptian Red Sea coast, has been a popular diving destination for about 20 years (Fig. 1). Since 1986 facilities for tourism have undergone rapid expansion and by the time of this study (1989–90) the number of visitors was greater than at any time in the past. Diving and snorkelling are the major recreational activities, others being unimportant by comparison.

Sharm-el-Sheikh was an ideal location for the study because coastal topography restricts shore access at many diving sites. Consequently, divers use a narrow path (approximately 20 m wide) to cross the reef-flat from the shore to the reef edge. Such paths are subject to heavy trampling, whilst comparable adjacent areas receive little trampling.

Two sites were used for this study: Ras Umm Sidd and The Tower (Fig. 1). A separate survey ranked them among the most heavily used in the area (Hawkins & Roberts, in press). Diver access routes constituted the heavily-trampled areas and these were matched with little-trampled control areas (hereafter termed trampled and untrampled for brevity). Factors other than trampling, such as depth of the reef-flat, were matched as closely as possible in siting control areas. The control area at Ras Umm Sidd was the adjacent headland about 1 km away (Fig. 1). Here the reef-flat structure was similar, the aspect almost the same, and diver

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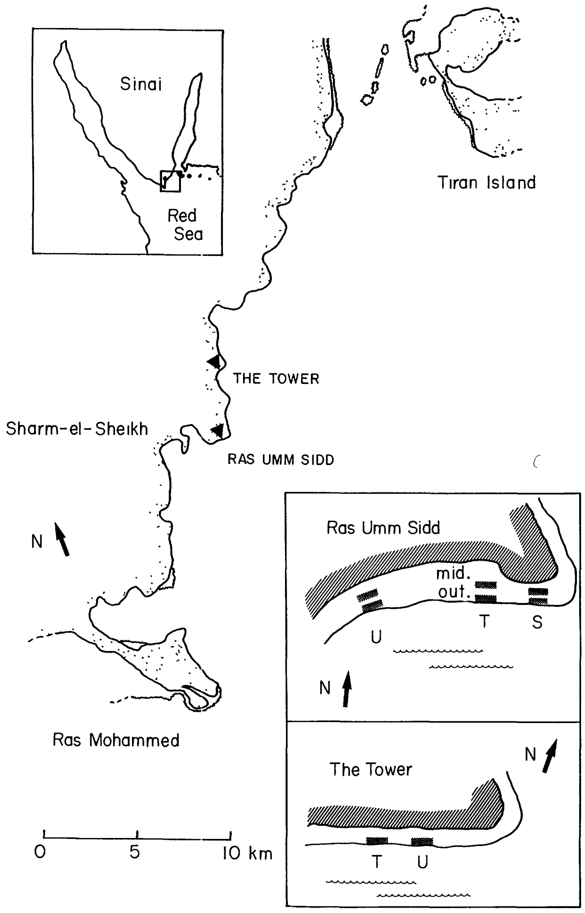

Fig. 1. Location of the study area and study sites. Lower right inset shows the location of treatments (shaded areas) within the two study sites (not to scale): T, trampled; S, snorkelled; U, untrampled; mid, middle zone; out, outer zone.

trampling virtually absent owing to the long and treacherous walk along the shore necessary to reach the site. This part of Ras Umm Sidd was sufficiently isolated that even snorkellers were rarely seen there.

In addition, a second control area was studied, approximately 40 m to the east of the trampled area (Fig. 1). This had a similar structure, but was a little more exposed to waves. Few divers walk on the reef-flat here because a low cliff (about 3 m high) borders the shore. However, it is commonly used by snorkellers, who swim across from the entry point at the trampled area.

The control area at The Tower was approximately 100 m to the east of the trampled area (Fig. 1). Reef-flat structure was very similar and aspect identical. Trampling by divers was very infrequent since access from the shore is blocked by a low cliff. However, there is a low level of use by snorkellers.

SAMPLING DESIGN

Sampling was carried out within a longshore-orientated 20×4 m area of reef for each treatment on both the middle and outer part of the reef-flat at Ras Umm Sidd (Fig. 1). The outer zone was defined as being within 4 m of the reef-edge, and the middle zone located within the middle of the reef-flat. At The Tower, where the reef-flat was approximately a quarter the width at Ras Umm Sidd, only the outer zone was sampled (Fig. 1). Here this was confined to within 2 m of the reef-edge (20×2 m) because coral growth further inshore was sparse.

Within the defined areas, coral communities were sampled randomly using a 1×1 m quadrat whilst snorkelling. Random sampling was approximated by the observer swimming with eyes closed in a haphazardly chosen direction for a variable distance before placing the quadrat (with the constraint that no areas were resampled). Twenty quadrats were sampled within each treatment at each site. Numbers of hard coral colonies, species, colonies recently broken, live loose fragments and fragments re-attached to the substratum were counted. Where possible, corals were identified to species according to Veron (1986) and Scheer & Pillai (1983); otherwise the genus was recorded. Names used were in accordance with Sheppard (1987). The hydrozoans *Millepora platygyra* and *M. dichotoma* were included in the hard coral category.

Measurements were also made of the relief and maximum diameter of all hard coral colonies susceptible to trampling. Relief was defined as the maximum height attained above the substratum, and a susceptible coral was one in a position where it could be trodden on by a diver (i.e. not concealed in a crevice). The total percentage cover of hard coral was estimated visually, as was cover of the following growth forms: branching, massive, encrusting, plate and foliaceous corals. Percentage cover of soft coral, bare substrate and rubble were also estimated and numbers of tridacnid clams with an aperture >10 cm wide recorded.

Data were analysed using ANOVA having first been tested for normality with the Kolmogorov-Smirnov one-sample test. Percentages were arcsin square-root transformed.

In order to determine whether coral community structure was altered by trampling, percentage cover and species composition data were subjected to cluster analysis using the group average method with the Bray-Curtis similarity index for cover data and Jaccard index for presence–absence data.

Results

Table 1 shows the results of analyses of variance comparing parameters. At both sites damage was greatest in trampled areas, with numbers of broken corals, loose fragments of live coral and % cover of rubble significantly greater than in untrampled areas (Table 2). The % cover of hard coral was significantly greater in untrampled areas and there was less bare substrate (Table 2). Coral colonies were significantly

Table 1. Results of ANOVAS showing the effects of trampling on the reef-flat at Ras Umm Sidd (two-way) and The Tower (one-way). The direction of the effects for each parameter in each zone are indicated. For The Tower differences shown were significant as indicated by Fisher's Protected Least Squares Difference. However, no multiple range comparison was calculated for Ras Umm Sidd and differences shown were derived from treatment means, T, trampled; S, snorkelled; U, untrampled

	Ras Umm Sidd			
Parameter	Trampling	Zone	Trampling × zone interaction	The Tower Trampling
Broken hard coral	0·0001	NS	0·03	0·0001
Middle	U < S < T			
Outer	U < S < T			U < T
Fragments hard coral	0·04	NS	0·02	0·003
Middle	U < S < T			
Outer	U < T < S			U < T
Reattached hard coral	NS	NS	NS	NS
Colonies hard coral	0·006	0·001	0·002	0·0001
Middle	T = S < U	Mid < Out		
Outer	T < U < S			T < U
Species hard coral	0·006	0·0001	NS	NS
Middle	U < T < S	Mid < Out		
Outer	U = T < S			
Hard coral cover	0·0001	0·0001	NS	0·0001
Middle	T < S < U	Mid < Out		
Outer	T < S < U			T < U
Soft coral cover	0·0001	0·0001	0·02	NS
Middle	T < U < S	Out < Mid		
Outer	T < U < S			
Clams	0·01	NS	NS	NS
Middle	S < T < U			
Outer	T < S < U			
Bare substrate	0·0003	0·002	0·004	0·0001
Middle	S < U < T	Mid < Out		
Outer	U < S < T			U < T
Rubble	0·003	0·0001	NS	0·0007
Middle	U < T < S	Out < Mid		
Outer	U < S < T			U < T
Height hard coral	0·0001	0·03	NS	0·02
Middle	T = S < U	Mid < Out		
Outer	T < S < U			T < U
Diameter hard coral	0·0001	0·0001	0·03	0·0006
Middle	T = S < U	Mid < Out		
Outer	T < S < U			T < U

larger in untrampled areas having both greater average heights and diameters (Table 3). They were also significantly more numerous in untrampled areas. For three parameters (number of clams, number of species of hard coral, and % soft coral cover) there was a significant difference between trampled and untrampled areas at Ras Umm Sidd, but not at The Tower.

There was no difference in damage between the two zones at Ras Umm Sidd (Table 1). All other parameters except the number of clams differed significantly. Such differences could explain why the effects of trampling were dissimilar between zones for some parameters (significant trampling × zone interaction, Table 1); for example, number of coral colonies, % soft coral cover and % bare substrate. That is, differences in benthic composition apparently affect susceptibility to trampling.

COMPARISON OF CORAL GROWTH FORMS

Figure 2 illustrates different coral growth forms as a proportion of the total hard coral cover found within each area sampled. At both sites, relative proportions of growth forms differed little between trampled and untrampled areas. However, at Ras Umm Sidd there were considerable differences between zones, particularly in the relative proportions of branching and massive corals.

A cluster analysis based on the % cover of different coral growth forms supported the above findings. If trampling affects % cover of the growth forms present then quadrats from trampled and untrampled areas should separate into different clusters. However, composition of the five clusters defined did not show any pattern based on sampling area (zone or treatment), suggesting that trampling

Table 2. Summary of the effects of trampling on the reef-flat. Figures shown are means for 20 1 × 1 m quadrats in each treatment. Figures for Ras Umm Sidd are for the outer zone only

	Tower		Ras Umm Sidd		
Parameter	Trampled	Untrampled	Trampled	Snorkelled	Untrampled
Number of broken coral colonies	2·6	0·5	5·7	2·0	0·5
Number of live loose coral fragments	1·0	0·1	0·9	2·4	0·5
Number of reattached fragments of hard coral	0·1	0·0	0·1	0·1	0·2
Number of clams	0·3	0·2	0·1	0·3	0·8
Number of hard coral colonies	28·6	42·4	28·1	39·6	30·2
Number of species hard coral	11·8	12·5	10·8	12·2	10·5
% hard coral	10·4	26·6	15·1	17·3	29·5
% soft coral	0·7	2·7	0·2	2·8	0·5
% bare substrate	87·4	70·5	82·8	78·2	69·3
% rubble	1.4	0·1	1·8	1·6	0·5

Table 3. Mean coral colony heights and diameters on the reef-flat within each zone and treatment at Ras Umm Sidd and The Tower. Results of ANOVAS on these parameters are shown in Table 1

Site, zone & treatment	Mean colony height (cm)	Mean colony diameter (cm)
Ras Umm Sidd		
Middle trampled	1·8	6·5
Middle snorkelled	1·9	6·6
Middle untrampled	2·6	9·0
Outer trampled	1·7	7·4
Outer snorkelled	2·2	8·2
Outer untrampled	3·1	13·1
The Tower		
Trampled	1·7	7·3
Untrampled	2·1	8·9

did not alter relative abundances of different coral morphologies.

EFFECTS OF TRAMPLING ON SPECIES COMPOSITION

A cluster analysis was also performed using coral species presence/absence data from the quadrats. Again composition of the three clusters defined did not relate to trampling intensity, suggesting that trampling did not influence coral community composition. The major differences were between sites and zones, suggesting that reef zone and location have a greater effect on species composition than trampling.

Discussion

Heavy trampling by divers appears to have altered coral population structure on the reef-flat. Coral colonies in trampled areas were smaller on average than in untrampled areas and there were fewer coral colonies and lower hard coral cover. The predominance of smaller, often stockier corals in heavily-trampled areas could be caused by increased mortality rates, or slower growth rates. Repeated tissue damage from trampling will require corals to allocate energy to tissue repair which might otherwise have been used for growth and reproduction. When Kay & Liddle (1987) broke coral colonies on the Great Barrier Reef, they found that although 2 months later nearly 100% had survived the damage, growth rates of two of three species had decreased. They acknowledged that 2 months might not have been long enough to be a useful measure of survival and suggest that the life expectancy of broken colonies could have been altered. Studies of terrestrial ecosystems have shown similar effects of trampling with decreases in plant height, cover, number of individuals and biomass (Liddle 1991).

Qualitative observations of branching corals suggest that those in trampled areas had shorter, thicker branches. This may be an effect of trampling and could reduce further damage as would having a denser skeleton. Chamberlain (1978) and Bottjer (1980) showed that wave action can increase skeletal density in corals.

Intensive trampling over a long period might be expected to exert an effect at the community level, e.g. reducing cover of branching corals, because these are the most susceptible to breakage (Kay & Liddle 1989). However, at least 15 years of heavy use by tourists does not appear to have affected community composition at Ras Umm Sidd or The Tower. By contrast, community effects have been documented elsewhere. Kay & Liddle (1989), in a study of trampling on the Great Barrier Reef found that 'open arborescent' corals were significantly less abundant on trampled transects on the outer reef-flat. However, they did not find a change in coral community composition on the reef crest.

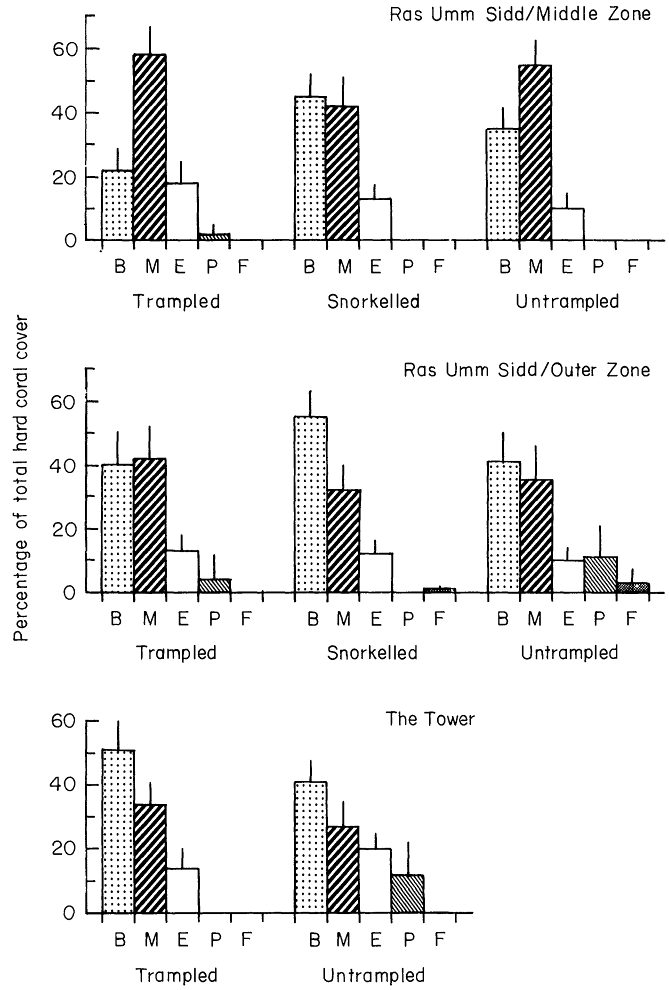

Fig. 2. Mean cover (±95% CI, $n = 20$ 1 × 1 m quadrats) of different coral growth forms in trampled, snorkelled and untrampled areas, expressed as a percentage of the total hard coral cover in each quadrat: B, branching; M, massive; E, encrusting; P, plate; F, foliaceous.

Our classification of a branching coral was more general than that used by Kay and Liddle, who had five different categories for this growth form. Corals in their 'open arborescent' category were very fragile, and such growth forms were not present on our reef-flat sites. In a previous study Kay and Liddle (unpublished report) concluded that trampling did not significantly reduce cover of any individual species, although they did note that branching *Acropora* species bore the brunt of the damage. Woodland & Hooper (1977) at Heron Island on the Great Barrier Reef, observed that cover of branching species was greatly reduced by trampling while most of the more robust massive colonies survived.

The reef-flat is an extreme environment and as such is mostly inhabited by species able to colonize bare substrata rapidly and reach reproductive maturity quickly. In the Red Sea these '*r*' strategists are predominantly fast-growing branching species, such as *Stylophora pistillata* (Loya 1976) and *Pocillopora verrucosa* (Ross 1984), which were the dominant species recorded on the reef-flat. Hence, although a branching morphology may be disadvantageous with respect to trampling resistance, life-history strategies adapted to existence in disturbed habitats can mean that branching corals are able to persist and flourish in trampled areas.

Fragmentation is an important means of reproduction in some species of coral (Highsmith 1982). However, there were no significant differences in numbers of re-attached fragments between trampled and untrampled areas in the present study. In contrast, heavily dived areas at 15 m deep on the fore-reef slope at Ras Umm Sidd and The Tower contained significantly more re-attached fragments than control areas (Hawkins & Roberts, 1992). Greater turbulence on the reef-flat probably sweeps fragments shorewards before they have the chance to become re-established. From their work on the Great Barrier Reef, Kay & Liddle (1989) suggest that '10% of the coral fragments on the reef crest and 19% on the outer reef-flat might survive and form new colonies'. In a previous study, survival of detached fragments differed among species and was dependent on size, smallest fragments having the least chance of survival (Kay & Liddle 1987).

The present study provided some evidence to confirm Kay & Liddle's (1989) finding that different zones of the reef-flat vary in their susceptibility to damage. In their study, reef crest coral communities were more resistant to trampling damage than those in the outer reef-flat. They attributed this to 'differences in the morphologies of the corals and the structure of the dead coral substrates between the two zones'.

The present study also confirmed Kay and Liddle's finding of significantly more bare substrate and rubble in trampled than untrampled areas. However, they noted that on the reef crest rubble did not accumulate but was swept away by waves.

The snorkelled zone at Ras Umm Sidd was interesting because it exhibited intermediate levels of damage between trampled and untrampled areas. Damage was very patchy: badly damaged in parts, fairly pristine in others. This can be explained from observations of snorkellers' behaviour. Usually they float face down causing little damage. However, when snorkellers stand up, the damage caused by cumbersome, uncontrolled fins can be severe. Unlike trampling by divers, which followed a narrow path across the reef, the activities of snorkellers were distributed over a much wider area of reef-flat. In a study in the Virgin Islands National Park, Rogers (1988) concluded that snorkellers caused considerable damage to corals by 'bumping into them or standing on them'.

Apart from the effects of trampling, tourist pressure may have other consequences. A small proportion of visitors kill clams and feed them to fish. Others kill them for trophies or to eat. This could partly explain the higher clam abundance in untrampled areas in both middle and outer zones at Ras Umm Sidd. Clams were overall less common at The Tower where there was no significant difference in abundance detected between trampled and untrampled areas. Coral collecting is banned in Sharm-el-Sheikh, and very few tourists attempt to break this law. None of the study areas appeared affected by this activity.

In addition to the deleterious biological effects shown by this study, trampling reduced the aesthetic appeal of the reef-flat for the many snorkellers who use it. Trampled areas supported less attractive coral communities than untrampled areas, appearing rather barren by comparison. For management purposes it may therefore be better to contain trampling within limited areas as occurred naturally at the study sites, rather than allow unrestricted access by divers across the reef-flat. Such an approach would minimize biological effects whilst preserving amenity value.

Acknowledgements

This study was undertaken during the Liverpool/Suez Canal Universities Joint Marine Biology Project. Staff of both universities are thanked for the use of facilities. Richard Hartnoll provided helpful comments on the study design; Barbara Brown, Alisdair Edwards and Andrew Price improved earlier drafts of the manuscript.

References

Bottjer, D.J. (1980) Branching morphology of the reef coral *Acropora cervicornis* in different hydraulic regimes. *Journal of Paleobiology*, **54**, 1102–1107.

Chamberlain, J.A. (1978) Mechanical properties of coral skeleton: compressive strength and its adaptive significance. *Paleobiology*, **4**, 419–435.

Hawkins, J.H. & Roberts, C.M. (1992) Effects of recreational scuba diving on fore-reef slope communities of coral reefs. *Biological Conservation*. **62**, 171–178.

Hawkins, J.H. & Roberts, C.M. (in press) Can Egypt's coral reefs support ambitious plans for diving tourism. *Proceedings 7th International Coral Reef Symposium, Guam, 1992*.

Highsmith, R.C. (1982) Reproduction by fragmentation in corals *Marine Ecology Progress Series*, **7**, 207–226.

Kay, A.M. & Liddle, M.J. (1987) Resistance, survival and recovery of trampled corals on the Great Barrier Reef. *Biological Conservation*, **42**, 1–18.

Kay, A.M. & Liddle, M.J. (1989) Impact of human trampling in different zones of a coral reef flat. *Environmental Management*, **4**, 509–520.

Liddle, M.J. (1991) Recreation ecology: effects of trampling on plants and corals. *Trends in Ecology and Evolution*, **6**, 13–17.

Loya, Y. (1976) The Red Sea coral *Stylophora pistillata* is an *r* strategist. *Nature*, **259**, 478–480.

Rogers, C.S. (1988) Damage to coral reefs in Virgin Islands National Park and Biosphere Reserve from recreational activities. *Proceedings of the Sixth International Coral Reef Symposium*, **2**, 405–410.

Ross, M.A. (1984) A quantitative study of the stony coral fishery in Cebu, Philippines. *Marine Ecology*, **5**, 75–91.

Salm, R.V. (1986) Coral reefs and tourist carrying capacity: the Indian Ocean experience. *UNEP Industry and Environment 1986 Jan/Feb/Mar* pp. 11–14. UNEP, Nairobi, Kenya.

Scheer, G. & Pillai, C.S.G. (1983) Report on the stony corals from the Red Sea. *Zoologica*, **133**, 1–198.

Sheppard, C.R.C. (1987) Coral species of the Indian Ocean and adjacent seas: a synonymized compilation and some regional distribution patterns. *Atoll Research Bulletin*, **307**, 1–32.

Tilmant, J.T. (1987) Impacts of recreational activities on coral reefs. *Human Impacts on Coral Reefs: Facts and Recommendations* (ed. B. Salvat), pp. 195–214. Antenne Museum E.P.H.E., French Polynesia.

Veron, J.E.N. (1986) *Corals of Australia and the Indo-Pacific*. Angus & Robertson. North Ryde, Australia. 644 pages.

Ward, F. (1990) Florida's coral reefs are imperiled. *National Geographic*, July, 115–132.

Woodland, D.J. & Hooper, N.A. (1977) The effect of human trampling on coral reefs. *Biological Conservation*, **11**, 1–4.

Received 28 June 1991; revision received 4 February 1992